

# Evolution of magnetic field in interacting galaxies

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## Abstract

Not much is currently known about how galaxy interactions affect an evolution of galactic magnetic fields. Here, for the first time, we explore a global evolution of magnetic fields with the advance of interaction process.

## 1 Introduction

Up to now, properties of magnetic fields were studied in detail only for one merging system – the Antennae galaxies (Chyży & Beck 2004). This is one of the best known pair of interacting objects. Even though it is still debatable how advanced is this system in the process of merging. According to the most recent studies the galaxies are already after the second encounter and not after the first one, as was considered earlier (Karl et al. 2010). The most unusual magnetic fields in the Antennae system are those strong and regular ones in between galaxies – in the overlapping region. Strong regular fields are also at the base of a tidal tail, from where they are stretched and transported along the tidal tail into the intergalactic medium. In this system magnetic fields are two times stronger than in typical spirals.

The evolution of interacting galaxies was studied for the first time about 40 years ago by Toomre & Toomre (1972). Their simulations of gravitational interactions between galaxies were used to construct a sequence of particular stages in the merging process, known now as a Toomre sequence (Toomre 1977). It constitutes eleven pairs of galaxies arranged from earlier to later stages of interactions. For each pair a number from one to eleven is assigned. Numbers from one to nine describe systems before the merger. The Antennae system is the first in this sequence. Number ten is assigned to a system at the stage of nuclear coalescence, and eleven describes the merger remnant.

## 2 The sample

The Toomre sequence was the base of our sample of interacting systems. In addition we selected galaxies from the sample constructed by Brassington et al. (2007) who investigated evolution of X-ray emission during the merging process. Furthermore, we performed some more general search for angularly large interacting galaxies and selected those for which radio data were available in the VLA archive. In total we selected 16 interacting systems. For each of the selected objects we assigned a corresponding number from the Toomre sequence. We call it the Interaction Stage. To describe all our galaxies we extended the Toomre sequence to earlier stages of interactions and assigned them number  $-1$  or  $0$ . They are the weakest interacting objects which usually show only weak tidal distortions in optical light or in HI distribution. For galaxies at more advanced stages than the Toomre galaxies we assigned

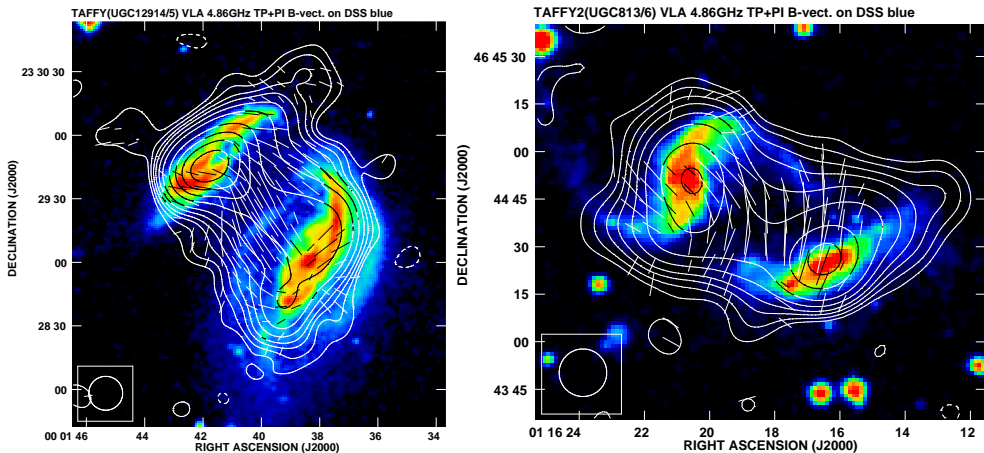


Figure 1: Left: Total power radio continuum map of the Taffy (UGC 12914/UGC 12915) at 4.86 GHz with superimposed B-vectors of polarization intensity, overlaid upon the DSS blue image. Right: Total power radio continuum map of the Taffy2 (UGC 813/UGC 816) at 4.86 GHz with superimposed B-vectors of polarization intensity, overlaid upon the DSS blue image.

numbers 12 and 13. The last system with number 13 is a proto-elliptical galaxy, NGC 1700 which was studied by Brassington et al. (2007).

### 3 The Taffy and The Taffy2

One of the most interesting interacting systems in our sample are Taffy and the Taffy2 galaxy pairs. The unusual radio bridges between galaxies in these objects were discovered by Condon et al. (1993) and Condon et al. (2002). We re-reduced once again their radio observations to look for remnants of magnetic field structures in the galactic disks. We indeed found them (as in the Antennae system), they are especially well visible, in UGC 12915 and similarly in UGC 816 (Fig. 1). However, the most intriguing are the directions of B-vectors in both radio bridges of the taffies. The directions of B-vectors in the Taffy are aligned along the radio bridge, whereas in the Taffy2 they are perpendicular to the line joining both galaxies. There are three reasonable possibilities which can explain this finding: differences in ages of both systems, a difference in energy involved in collisions, and a complicated morphology of magnetic fields in the bridges. However, to evaluate these possibilities and solve that puzzle more detailed MHD simulations are needed.

### 4 Magnetic field strength and regularity

The derived for our sample of interacting galaxies total magnetic field strengths are ranging from  $5 \mu\text{G}$  for Arp 222 to  $27 \mu\text{G}$  for Arp 220. These calculations were performed assuming the equipartition between magnetic fields and cosmic rays (Beck & Krause 2005). The mean value of magnetic field computed for the whole sample is  $14 \pm 5 \mu\text{G}$ . It is higher than the value

reported by Niklas (1995) for his sample of galaxies of various Hubble types. In contrast to the total magnetic field the strength of the regular field is like in other galaxies. However, the field regularity, which is the ratio of regular and random field components, is lower than in typical galaxies (cf. Beck et al. 1996). This implicates, that the random component of the magnetic field is more efficiently produced in interacting galaxies than in normal spirals. Or the regular component is destroyed more efficiently by processes related to strong star formation.

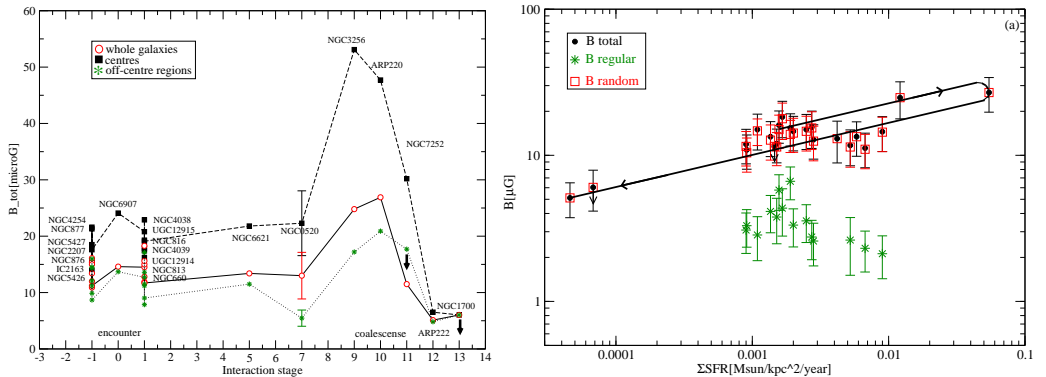


Figure 2: Left: The evolution of magnetic field strength in interacting galaxies. Mean magnetic field strengths are given for the whole galaxies (circles), centres (squares), and off-centre regions (asterisks). Arrows indicate upper limits of the field strength. Two special stages of interaction are denoted: the first galaxy encounter and the coalescence of the merger nuclei. The error bar for NGC 520 is shown. Right: Total magnetic field strengths (circles) versus surface density of SFRs for the whole interacting galaxies. The random and regular components of magnetic fields are also provided (squares and asterisks, respectively). An expected evolutionary track of interacting systems is also indicated (from Drzazga et al. 2011).

## 5 Magnetic field evolution

Are the strengths of galactic magnetic fields in any way related to the Interaction Stages? In figure 2 the strength of total magnetic field obtained for our sample is plotted against the Interaction Stage. A general evolution of the magnetic fields is seen: for weakly interacting galaxies, shown in the left part of the plot, the magnetic field is nearly constant, with some dispersion. However, when interaction advances the magnetic field strength is increasing and reaches the maximum value for the systems being close to the stage of nuclear coalescence. After the nuclear coalescence the opposite trend is visible, the magnetic field is quickly weakening, indicating that the main processes responsible for generation of magnetic fields terminate at this stage. Such evolutionary trend is observable for the whole galaxies, their centres, and for off-centre regions. The largest enhancement of the magnetic field strengths is visible at galactic centres. This is in agreement with the finding of Hummel (1981) that the main increase of the radio emission of interacting galaxies, when compared to non-interacting objects, occurs in their centres.

Similar evolutionary trend was also found by Georgakakis et al. (2000) for star formation efficiencies. This implicates, that the main source which regulates the generation processes of magnetic fields in the gravitationally interacting galaxies is related to the intensity of the star formation process. To check this hypothesis we determined relations between the total magnetic field strength, its random and regular components, and the star formation surface density ( $\Sigma SFR$ ) – computed from the IRAS fluxes at 60 and 100  $\mu\text{m}$  (Fig. 2). Such dependencies were constructed for the whole galaxies, nuclear regions and off-centre regions (see, Drzazga et al. 2011). We found, that there is some weak relation for the total and random fields. The correlation coefficient determined for the whole disks and off-centre regions is about 0.49. It is worth to note, that the obtained relations are strongly controlled by galaxies of the highest and lowest  $\Sigma SFR$ s. In the intermediate range of  $\Sigma SFR$  galaxies with completely different interaction stages meet together, as indicated by the evolutionary track in figure 2. Thus, the full evolution of the magnetic field in the interacting galaxies can only be seen when they are arranged along the interaction stage.

## 6 Conclusions

For the studied sample of 16 systems of gravitationally interacting galaxies we obtained the following results:

- the estimated mean of total magnetic field strength is  $14 \pm 5 \mu\text{G}$ , which is larger than for the non-interacting objects – this seems to be caused by enhanced production of random field component;
- for the first time, we show a global evolution of magnetic fields with the advance of interaction process. The main production of magnetic fields terminates close after the nuclear coalescence. The strength of magnetic fields in interacting galaxies is controlled by the intensity of star formation.

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## References

- Beck, R., Brandenburg, A., Moss, D., Shukurov, A., & Sokoloff, D. 1996, *ARA&A*, 34, 155
- Beck, R., & Krause, M. 2005, *AN*, 326, 414
- Brassington, N. J., Ponman, T. J., & Read, A. M. 2007, *MNRAS*, 377, 1439
- Chyży, K. T., & Beck, R. 2004, *A&A*, 417, 541
- Condon, J. J., Helou, G., Sanders, D. B., & Soifer, B. T. 1993, *AJ*, 105, 1730
- Condon, J. J., Helou, G., & Jarrett, T. H. 2002, *AJ*, 123, 1881
- Drzazga, R. T., Chyży, K. T., Jurusik, W., Wiórkiewicz, K. 2011, *A&A*, 533, 22
- Georgakakis, A., Forbes, D. A., & Norris, R. P. 2000, *MNRAS*, 318, 124
- Hummel, E. 1981, *A&A*, 96, 111
- Karl, S. J., Naab, T., Johansson, P. H., Kotarba, H., Boily C. M., et al. 2010, *ApJ*, 715, L88
- Niklas, S. 1995, PhD thesis, University of Bonn
- Toomre, A., & Toomre, J. 1972, *ApJ*, 178, 623
- Toomre, A. 1977, *Evolution of Galaxies and Stellar Populations*, Proceedings